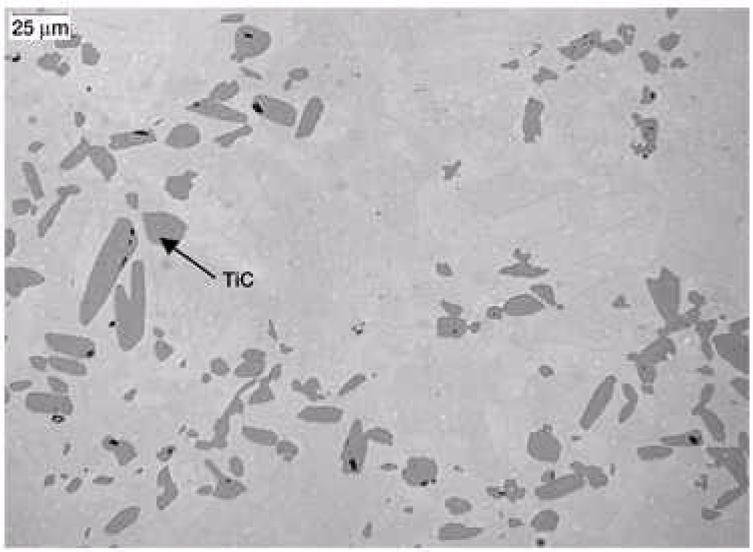
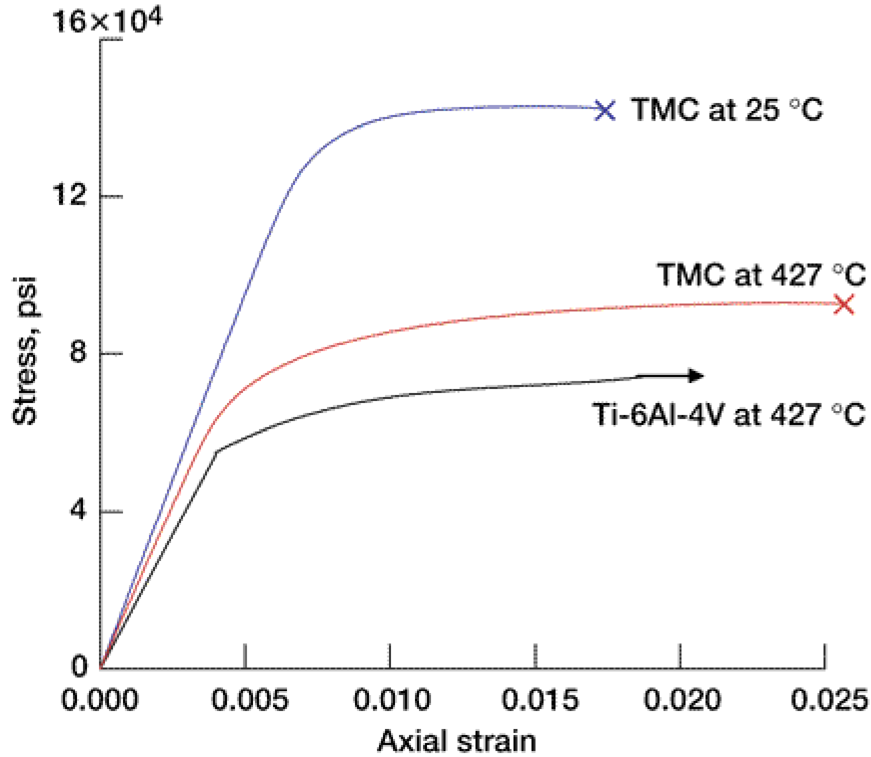
Particulate Titanium Matrix Composites Tested-Show Promise for Space Propulsion Applications

New manufacturing technologies can now produce uniformly distributed particle-strengthened titanium matrix composites (TMCs) at lower cost than many types of continuous-fiber composites. The following photomicrograph shows one such TMC. The innovative process results in near-final-shape components having a material stiffness up to 26-percent greater than that of components made with conventional titanium materials. This benefit is achieved with no significant increase in the weight of the component. The improved mechanical performance and low-cost manufacturing capability motivated a review of particulate-reinforced metal composite technology as a way to lower the cost and weight of space-access propulsion systems.



Distribution of titanium carbide particles in a matrix of titanium alloy, Ti-6Al-4V.

Focusing on the elevated-temperature properties of titanium alloy Ti-6Al-4V as the matrix material, researchers at the NASA Glenn Research Center conducted experiments to verify the improved performance of the alloy containing 10 wt% of ceramic titanium carbide (TiC) particles. The appropriate blend of metal and ceramic powder underwent a series of cold and hot isostatic pressing procedures to yield bar stock. A set of round dog-bone specimens was manufactured from a small sample of the bars. The TMC material proved to have good machinability at this particle concentration as there was no difficulty in producing high-quality specimens.



The stress-strain response of titanium matrix composite at room temperature and 427 °C in comparison to Ti-6Al-4V alloy at 427 °C. Strain rate, 0.001.

Long description of figure 2 The stress-strain response of a titanium matrix composite at room temperature and 427 °C in comparison to Ti-6Al-4V alloy at 427 °C. The initial linear portion of the curves show that the composite response has a steeper slope. This reflects the greater stiffness of the composite material. The magnitude of stress where nonlinear behavior initiates, the yield point, is greater for the composite material.

.

Tensile and low-cycle fatigue testing was done at 427 °C, a benchmark test temperature common to several previous titanium test programs. At the relatively low particle concentrations used in these tests, the material stiffness of the TMC was improved 19 percent over that of the plain Ti-6Al-4V alloy when tested at 427 °C. As the stress-strain curve in the preceding graph shows, the yield strength and tensile strength of the composite are 23- and 14-percent greater than those of the plain alloy. However, the composite's greater strength is offset by a ductility reduced by one-fifth and a fatigue life reduced by one-third of the plain alloy's property. This is expected because the ceramic particles act as stress risers in the matrix material. Although operational life is reduced relative to the unreinforced material, it is noteworthy that low-cycle fatigue at 1-percent strain range does not degrade the composite's superior material stiffness. At these temperature levels and for stiffness-driven applications, particulate-reinforced TMC is an attractive alternative to other lightweight materials, such as aluminum matrix composites and carbon-fiber-reinforced polymers. The completion of the exploratory study resulted in the selection of 10 wt% titanium carbide composite CermeTi (Dynamet Technology, Inc., Burlington, MA) for more rigorous evaluation of its deformation, long-term fatigue, and durability.

In this regard, an experimental program has been designed including tensile and compression static, creep and relaxation, and low- and high-cycle fatigue studies. The specimen geometries were selected to investigate the influence of lateral constraint and notch sensitivity. The literature indicates that metal matrix composites perform well in high-cycle fatigue and that reduced lateral constraint may also be beneficial. Verification of such characteristics would be useful to propulsion system designers seeking to employ this material in future applications. Finally, the resulting data will also support the development of a fundamental understanding of metal matrix composites operating at elevated temperatures and should lead to the development of a constitutive model for these materials.

Ohio Aerospace Institute (OAI) contact: Dr. John C. Thesken, 216-433-3012, John.C.Thesken@grc.nasa.gov
Glenn contacts: Dr. Bradley A. Lerch, 216-433-5522, Bradley.A.Lerch@nasa.gov; and Dr. Steven M. Arnold, 216-433-3334, Steven.M.Arnold@nasa.gov
Authors: Dr. John C. Thesken, Dr. Bradley A. Lerch, and Dr. Steven M. Arnold
Headquarters program office: OAT
Programs/Projects: HOTPC, Gen 3
Special recognition: 2002 Space Flight Awareness Team Award given for outstanding support given to the Rotor Safe Life Program for developing a basic understanding of time-dependent behavior of preloaded composite flywheel rotors for the International Space Station